PICES Scientific Report No. 28
2005

REPORT OF THE STUDY GROUP ON FISHERIES AND ECOSYSTEM RESPONSES TO RECENT REGIME SHIFTS

Edited by

Jacquelynne R. King

January 2005
Secretariat / Publisher
North Pacific Marine Science Organization (PICES)
c/o Institute of Ocean Sciences, P.O. Box 6000, Sidney, B.C., Canada. V8L 4B2
E-mail: secretariat@pices.int Home Page: http://www.pices.int

2. Coherent Regional Responses

Lead Author: Jacquelynne King

Contributing Authors: Harold Batchelder, Jennifer Boldt, William Crawford, Anne Hollowed, Suam Kim, Victor Lapko, Alec MacCall, David Mackas, Nathan Mantua, Gordon McFarlane, Stewart McKinnell, James Overland, Ian Perry, Jeffrey Polovina, Jacob Schweigert, Franklin Schwing, Qi-Sheng Tang, Akihiko Yatsu, and Jin-Ping Zhao

2.1 Introduction

The Pacific basin-wide changes in climate and ocean parameters are reported in Section 1. To describe specific regional responses to the basin-wide changes, we divided the North Pacific into five major regions (Fig. 2.1): the central North Pacific, which includes the transition zone and the Hawaiian Islands; the California Current System from California up to northern Vancouver Island; the Gulf of Alaska system from northern Vancouver Island to the start of the Aleutian Islands, including the central Gulf region; the Bering Sea and Aleutian Islands; the western North Pacific, which includes the Sea of Okhotsk, the Tsushima Current region, the Kuroshio/Oyashio Current region, the Yellow Sea and the East China Sea. Regional responses were detected in physical oceanographic parameters such as temperature and salinity, and in organisms at both lower trophic levels (phytoplankton, zooplankton, and invertebrates) and at higher trophic levels, including fishes and marine mammals. Detailed descriptions of the observed regional responses to the 1998 basin-wide shift are provided in Appendices 1–5.

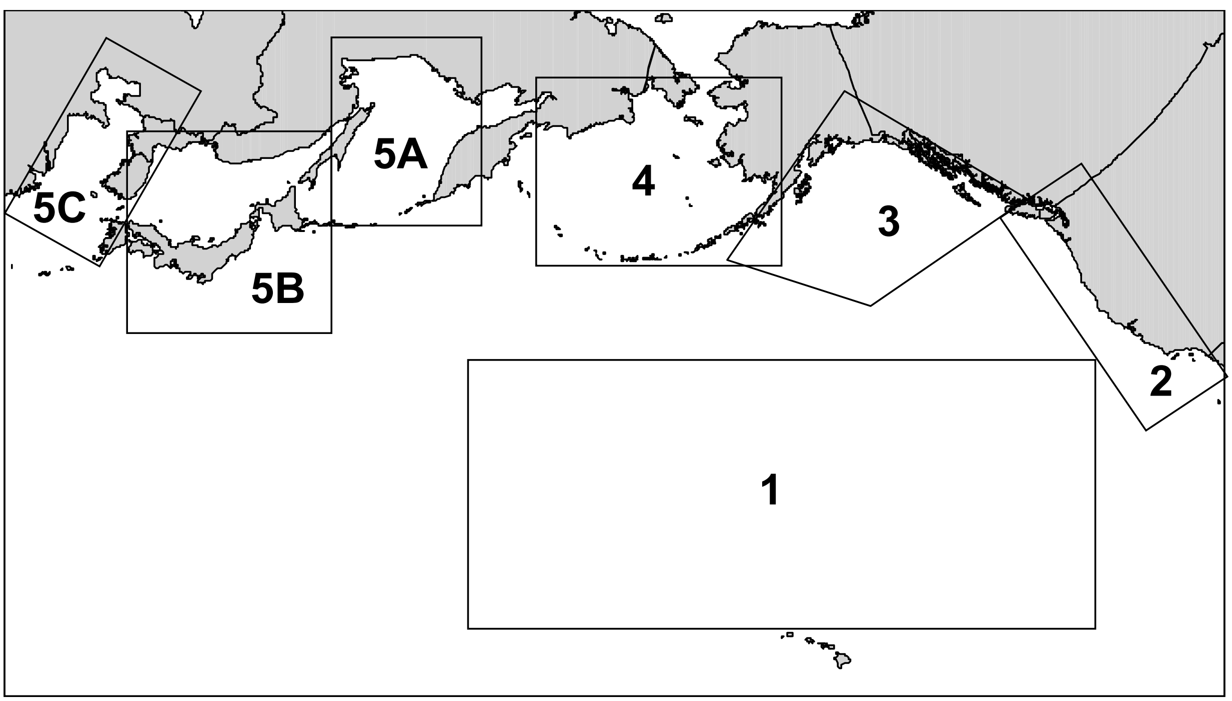

Fig. 2.1 Designation of the five regions of the North Pacific for which ecosystem responses are reported: (1) central North Pacific; (2) California Current System; (3) Gulf of Alaska; (4) Bering Sea and Aleutian Islands: (5) western North Pacific comprised of (A) Sea of Okhotsk, (B) Tsushima Current region and Kuroshio/Oyashio Current region and (C) Yellow Sea and East China Sea.

2.2 Central North Pacific (CNP)

The central North Pacific experienced an abrupt change, beginning in 1999, characterized by a rise in sea surface height (SSH), indicating an increase in the depth of the top of the thermocline. At the same time the eastern and northern boundaries of the North Pacific experienced a drop in SSH, indicating a shoaling of the depth of the top of the thermocline. In the central North Pacific, the SSH rise was accompanied by a northward shift of low surface chlorophyll water. At higher trophic levels, Hawaiian monk seal pup survival at northern atolls in the Northwest Hawaiian Islands dropped since 1999. Also, since 1999 the albacore fishing grounds for the U.S. troll fleet shifted eastward. By 2003, the high SSH anomaly in the central North Pacific had dissipated, suggesting it was a response to the 1999 La Niña rather than a decadal shift.

2.3 California Current System (CCS)

Conditions in the California Current System are subject to decade-scale regime behavior with an overlay of episodic warm El Niño and cold La Niña events that last a year or two. In the CCS, there have been strong ecosystem responses to the 1977 and 1989 regime shifts. The 1977 regime shift led to a protracted period of warm surface waters, with a deepening of the thermocline and the implication of lower productivity. However, available zooplankton time series suggest that salp biomass declined after 1977, while euphausiid biomass remained unchanged and copepod biomass actually increased. Following the 1977 regime shift, overall recruitment improved for species such as Pacific sardine, and other species experienced intermittent very strong year classes (Pacific hake and Pacific cod). After the 1989 regime shift, the warm surface waters intensified and became unproductive for many coastal species. In coastal waters, zooplankton shelf species were replaced by more southerly and oceanic species. Many fish species (Pacific salmon, Pacific hake, Pacific cod, and rockfish species) experienced almost a decade of poor recruitment. Southern migratory pelagics (Pacific sardines and Pacific hake) extended the northern limit of their distribution to northern British Columbia, and in some years, the Gulf of Alaska (GOA).

After an intense El Niño in 1998, the CCS experienced a very cold La Niña in 1999. Since 1999, sea surface temperatures (SSTs) have tended to return gradually toward warm conditions similar to those in the 1980s and early 1990s, but thermocline depths are now much shallower and nutrient levels are higher, generating higher primary and secondary production. Beginning in 1999, coastal waters saw a return of shelf zooplankton, and many coastal fish stocks experienced substantial improvements in year class success. Some stocks produced good year classes in 1999 (*e.g.*, Pacific hake), and recent returns of several salmon stocks have improved; Columbia River salmon runs have been extraordinary. In addition, the distribution of migratory pelagic fishes (Pacific sardine and Pacific hake) contracted to a more southerly distribution. There is growing evidence, based on a strong and diverse biological response, that a regime shift favoring coastal organisms occurred in 1998.

2.4 Gulf of Alaska (GOA)

Ecosystem responses to regime shifts in the GOA were strong after the 1977 shift, but weaker after the 1989 and 1998 shifts. Variation in the strength of responses to climate shifts may be due to the geographical location of the GOA in relation to the spatial pattern of climate variability in the North Pacific. Prior to 1989, climate forcing varied in an east–west pattern, and the GOA was exposed to extremes in this forcing. After 1989, climate forcing varied in a north–south pattern, with the GOA acting as a transition zone between the extremes in this forcing. The 1989 and 1998 regime shifts did not, therefore, result in strong signals in the GOA.

There were both physical and biological responses to all regime shifts in the GOA. However, the primary reorganization of the GOA ecosystem occurred after the 1977 shift. After 1977, the Aleutian Low intensified, resulting in a stronger Alaska current, warmer water temperatures, increased coastal rain and, therefore, increased water column stability. The optimal stability window hypothesis suggests that water column stability is the limiting factor for primary production in the GOA (Gargett 1997). A doubling of zooplankton biomass between the 1950s and 1960s, and in the 1980s, indicates that production was positively affected after the 1977 regime shift (Brodeur and Ware 1992). Recruitment and survival of salmon and demersal fish species also improved after 1977. Catches of Pacific salmon, recruitment of rockfish (Pacific ocean perch), and flatfish (arrowtooth flounder, halibut, and flathead sole) recruitment and biomass all increased. There are indications that shrimp and forage fish, such as capelin, were negatively affected by the 1977 shift, as survey catches declined dramatically in the early 1980s (Anderson 2003). The reduced availability of forage fish may have been related to the decline in marine mammal and seabird populations observed after the 1977 shift (Piatt and Anderson 1996).

After 1989, water temperatures were cooler and more variable in the coastal GOA, suggesting that production may have been lower and more variable. After 1989, British Columbia salmon catches and survival were low and herring declined in Queen Charlotte Islands (northern British Columbia). However, salmon catches in Alaska remained high. Groundfish biomass trends that began in the early 1980s continued, with increases in flatfish biomass. By the late 1980s, arrowtooth flounder, rather than walleye pollock, were dominant. Large groundfish biomass estimates resulted in negative recruit per spawning biomass anomalies of demersal fish.

There is some indication that the GOA ecosystem may have responded weakly to the 1998 regime shift. Increased storm intensity from 1999 to 2001 resulted in a deeper mixed layer depth in the central GOA, and coastal temperatures were average or slightly below average. After 1998, coho survival increased in British Columbia, shrimp catches increased in the northern GOA, and the 1999 year class of both walleye pollock and Pacific cod was strong in the northern GOA. Recruitment information from longer-lived species will be available in the near future, enabling scientists to determine if there were other responses to the 1998 climate shift.

It is apparent that many components of the GOA ecosystem respond to decadal-scale variability in climate and ocean dynamics. It is unknown if changes observed after the 1998 shift will persist in the GOA or how long the current conditions in the GOA will last. Predicting regime shifts will be difficult until the mechanisms that cause the shifts are understood. Monitoring indicator species is one method to improve our knowledge of the mechanisms that cause the shifts. Potential indicator species of regime shifts would include those that have a short life-span, are sensitive to changes, are key trophic groups, and/or are targeted by fisheries which produce data that are readily available. Examples of potential indicator species in the GOA that fit some of these criteria include sockeye and pink salmon, Pacific herring, juvenile fish abundance, ichthyoplankton, as well as zooplankton biomass and composition.

2.5 Bering Sea and Aleutian Islands

Bering Sea (BS)

There is no evidence of a shift in the Bering Sea system since 1977. The Bering Sea was subject to a change in the physical environment and an ecosystem response after 1977, a minor influence from shifts in Arctic atmospheric circulation in the early 1990s, and persistent warm conditions.

A major transformation, or regime shift, of the Bering Sea occurred in atmospheric conditions around 1977, changing from a predominantly cold Arctic climate to a warmer subarctic maritime climate as part of the Pacific Decadal Oscillation (PDO). This shift in physical forcing was accompanied by a major re-organization of the marine ecosystem on the Bering Sea shelf over the following decade. Fisheries surveys and model calculations show a shift in the importance of pollock to the ecosystem, from near 10% of the energy flow at mid-trophic levels in the 1950s–60s, to over 50% in the 1980s, although biological information for the earlier period is limited and often speculative. Weather data beginning in the 1910s, and proxy data (*e.g.*, tree rings) back to 1800, suggest that, except for a period in the 1930s, the Bering Sea was generally cool before 1977, with sufficient time for slow-growing, long-lived, cold-adapted species to adjust. Thus the last few decades appear to be a transition period for the Bering Sea ecosystem.

A specific Arctic influence on the Bering Sea began in the early 1990s, as a shift in polar vortex winds (the Arctic Oscillation – AO) reinforced the warm Bering Sea conditions, especially promoting an earlier timing of spring meltback of sea ice. Flatfish increased in the mid-1980s due to changes in larval advection, but the AO shift to weaker winds in the early 1990s reduced these favorable conditions for flatfish larval advection. Warm conditions tend to favor pelagic over benthic components of the ecosystem. Cold water species, *i.e.*, Greenland turbot, Arctic cod, snow crab and a cold water amphipod, are no longer found in abundance in the southeast Bering Sea, and the range of Pacific walrus is moving northward. While it is difficult to show direct causality, the timing of the reduction in marine mammals suggests some loss of their traditional Arctic habitat. Although ecological conditions appear to be mostly stable over the last decade, the warmest water column temperatures have occurred in 2001–03 on the southeast Bering Sea shelf, despite considerable year-to-year variability in the AO and PDO.

Overall climate change occurring in the Arctic, as indicated by warmer atmospheric and oceanic temperatures and loss of 15% of sea ice and tundra area over the previous two decades, is making the Bering Sea less sensitive to the intrinsic climate variability of the North Pacific. Indeed, when the waters off the west coast of the continental United States shifted to cooler conditions after 1998, the subarctic did not change (Victoria pattern), in contrast to three earlier PDO shifts in the twentieth century. Thus the Bering Sea will likely continue on its current warm trajectory, with biomes transitioning northward, allowing pollock a larger domain at the expense of cold- and ice-adapted species, rather than transitioning back to a cold regime.

Aleutian Islands (AI)

Climatic conditions vary between the east and west Aleutian Islands around 170°W: to the west there is a long-term cooling trend in winter, while to the east, conditions change with the PDO. This is also near the first major pass between the Pacific and Bering Seas for currents coming from the east. Biological conditions in the Aleutian Islands have changed since the 1980s, and it is too soon to discern if there was a change associated with the 1998 shift. Pollock and Atka mackerel do not appear to vary on a decadal scale. However, the biomass of pollock appears to be higher now than it was in the 1980s. Pacific ocean perch population dynamics vary on a decadal scale; for example, Pacific ocean perch survival changed at approximate times of regime shifts, 1977 and 1989. There is not enough information on the early life history of Pacific ocean perch to define a mechanism for the observed variations.

2.6 Western North Pacific (WNP)

Physical and biological data were summarized by three main regions: the Sea of Okhotsk; the Tsushima Current region and Kuroshio/Oyashio Current region; and the Yellow and East China Seas. The response to the 1989 regime shift was strong in all regions of the western North Pacific, from the East China Sea through to the Sea of Okhotsk, including the Kuroshio/Oyashio Current region. Winter air temperatures increased, which corresponded to warmer SSTs. These conditions have persisted to 2003 and appear to be connected to the east–west dipole pattern observed in basin-wide SST variability. A strong response to the 1998 regime shift was observed only in the Sea of Okhotsk, with an intensification of colder conditions and sea ice extent. This intensification corresponded to a persistent increase in Sea of Okhotsk zooplankton biomass in 1999, particularly in the spring, for large-sized plankton such as euphausiids, amphipods, copepods, and arrow worms. Changes in the epipelagic fish community were also evident, with Japanese sardine, previously a dominant species, replaced by herring, capelin and Japanese anchovy. Walleye pollock remained the most abundant species in the Sea of Ohkotsk, but the intensification of colder conditions in 1998 corresponded to a decrease in walleye pollock biomass. Consistent biological responses to the 1998 shift were not evident in the other western North Pacific regions. The biomass of warm water macro-algae in the Tsushima Current region increased when water temperatures increased in the late 1990s. Zooplankton biomass in the Kuroshio Current region has varied since 1978, but has remained at low levels. Conversely, zooplankton biomass in the eastern Yellow Sea has remained at high levels since the late 1990s. Phytoplankton and zooplankton biomass has declined in the Bohai Sea, the western Yellow Sea, and the East China Sea since the early 1980s. In both the Kuroshio and Tsushima Current areas, Japanese sardine began to decline in abundance around 1988. In contrast, Japanese anchovy, jack mackerel and Japanese common squid have increased in abundance since the mid-1980s. Most fish abundance and recruitment were normal in 1998, but recruitment of Japanese common squid and Pacific saury were extremely poor. Groundfish species in the Yellow Sea have declined in abundance from the 1960s to 1990s. Japanese common squid have increased and maintained high levels since the 1990s.

2.7 Coherence in Regional Responses to the 1998 Regime Shift

Although each region does not respond in the same manner to a regime shift, it is clear that regions do respond in some manner to most shifts. The 1998 regime shift had the greatest impact in the most southerly regions (*i.e.*, the central North Pacific and the California Current System) and had virtually no impact in the Bering Sea. It is important to note that the El Niño event in 2002–03 has produced a signal that may have confounded characterization of the new state. Table 2.1 provides a summary of the basin-wide climate–ocean indices (Section 1), and the physical and biological components of each region, which are reported in detail in Appendices 1–5. The table is intended to provide a single source of summary information of all of the indices and time series that were reviewed by the Study Group. For each data series, the overall state was characterized for regime periods to provide an indication of the nature of that climate, ocean or ecosystem component during previous regimes (1947–76; 1977–88; 1989–97). In a similar manner, each year subsequent to 1998 was also categorized to provide an indication of which components changed, when those components changed, and the impact of the 2002–03 El Niño event.

2.8 Climate Indicators for Detecting Regime Shifts

A number of indices and indicators are used operationally to quantify climate state and variability. These are derived principally from available long-term data and easy-to-monitor physical fields. Some of the indices relevant to identifying decadal climate variability are described in Section 1. For ecosystem variability, fishery-based and other biologically-based indicators should be used as well, although these are less developed. Because they are proven reasonable indicators of past regime shifts, the existing climate indices (*e.g.*, PDO, Victoria, Northern Oscillation Index) should continue to be tracked and used as indicators of changes in climate and North Pacific Ocean conditions. However, research should also continue on developing and testing the utility of new indicators.

Decadal climate variability in the North Pacific is not a two-state system represented by a single mode (*e.g.*, alternating cool/warm states), but is a result of more than one climate mode. It is not plausible to predict when the system will go back to the previous phase of a mode such as the PDO, because it may switch to a different mode. Furthermore, it is not possible to say when the next change will occur, but only to detect if a change has occurred in accordance to some criteria of a regime shift. The observational record is short relative to the time scale of regime shifts, so it is not certain if the modes observed this century are regular in timing and intensity. Furthermore, it is possible that additional modes of climate variability have existed in the past, prior to instrumented monitoring, but within the evolutionary scope of fish populations, and perhaps new patterns will become dominant as a result of future natural and anthropogenic climate change.

Existing indicators generally characterize basin-scale patterns. It is important to monitor physical changes at regional scales, and to use indices which represent fields or processes that directly affect fishery populations (*e.g.*, coastal upwelling, circulation, stratification) rather than a broad-scale index that may be integrating a number of different signals in different regions. On the other hand, while the historical sequence of regime shifts requires multiple indicators to fully explain basin-scale variability, it is more likely that a single indicator will consistently describe regional climate shifts.

Sea surface height and ocean color observed from satellites may be reliable regime indicators because they integrate many processes of ecological importance (thermal structure, circulation, primary production), and satellite technology makes these fields consistently and regularly available. Monitoring to develop and maintain indices that are more directly and intimately related to the productivity of a fishery population or ecosystem should be a high priority because these types of indices will be consistent in explaining biological variability – as opposed to the common indicators currently available which are merely proxies of the biological changes we seek to track. Finally, research should continue on identifying the mechanisms by which climate change leads to ecosystem response. Such efforts are critical if we are to efficiently recognize the signals that will produce the shifts in marine populations of importance to managers.

2.9 References

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Table 2.1 Summary table of basin-wide climate ocean indices and regional physical and biological parameters by regime period (1948–1976; 1977–1988; 1989–1997) and by year subsequent to 1998. For each item, the value or definition designated to the symbols ● and ○ (typically the extremes of the range of values or definitions) are indicated. In all cases, the symbol ◍ indicates moderate values, ⇗ indicates a period of increasing trend, ⇙ indicates a period of decreasing trend, ⇔ indicates no change in pattern or value and ⊗ indicates a period of variability in the parameter, *i.e.*, no apparent trend or persistent pattern.

	Length of time series	Regime 1948-1976	Regime 1977-1988	Regime 1989-1997	Year 1998	1999	2000	2001	2002	2003	2004	
Climate Ocean Indices												
Pacific Decadal Oscillation (winter)	1950-2004	●	○	○	○	◍	◍	◍	◍	○	◍	●=negative value; ○=positive value
Victoria pattern (winter)	1950-2004	⊗	◍	●	◍	○	○	○	○	◍	◍	●=negative value; ○=positive value
Arctic Oscillation	1950-2001	◍	●	○	○	⊗	⊗	⊗				●=negative value; ○=positive value
Northern Oscillation Index	1950-2003	○	●	●	●	○	○	○	○	●	◍	●=negative value; ○=positive value
Multivariate ElNiño-LaNiña Southern Oscillation Index	1950-2003	○	●	●	●	○	●	◍	◍	●	◍	●=negative value; ○=positive value
Central North Pacific												
Physical Oceanography												
Sea surface height	1992-2004			●	●	○	○	○	○	●	●	●=low height; ○=high height
Lower Trophic Levels												
Transition Zone Chlorophyll Front latitude	1997-2004			●	●	○	○	○	○	●	●	●=southerly; ○=northlerly
Fishes												
Albacore tuna fishery distribution	1995-2003			●	●	○	○	○	○	○		●=oceanic waters; ○=coastal waters
Higher Trophic Levels												
Kure/Midway monk seals	1995-2002			○	○	◍	●	●	●	◍		●=low pup survival; ○=high survival
California Current System												
Physical Oceanography												
Sea surface temperature	1900-2004	●	○	○	○	●	●	●	○	○		●=cool; ○=warm

	Length of time series	Regime 1948-1976	Regime 1977-1988	Regime 1989-1997	Year 1998	Year 1999	Year 2000	Year 2001	Year 2002	Year 2003	Year 2004	
Stratification intensity	1950-2003	●	⬀	○	⊗	●	◐	◐	◐	◐		●=weak; ○=strong
Mixed layer depth	1949-2004	●	⬃	○	⊗	●						●=shallow; ○=deep
Alongshore current strength	1949-2004	○	●	●	⊗	○	○	○	○	◐		●=weak; ○=strong
Upwelling strength	1946-2004		○	●	⊗	○	○	○	○	○		●=weak; ○=strong
Lower Trophic Levels												
Chlorophyll *a*	1978-1986; 1997-2003			●	●	○	○	○	○	○		●=low concentration; ○=high
Salp biomass	1952-2003	○	●	●	●	⬀	⬀	⬀	⬀	⬀		●=low; ○=high
Copepod biomass	1952-2003	◐	○	●	○	○	○	○	○	○		●=low; ○=high
Euphausiid biomass	1952-2003	⊗	⊗	⊗	●	◐	◐	◐	◐	◐		●=low; ○=high
Zooplankton composition – Core of the current	1952-2001	○	◐	●	●	◐	○	◐	◐	◐	◐	●=southern species; ◐=normal; ○=northern species
Zooplankton composition – Periphery zones	1969-2003	◐	◐	●	●	◐	○	◐	◐	◐	●	●=southern species; ◐=normal; ○=northern species
Invertebrates												
Squid catch	1981-2003			⬀	●	○	○	○	◐	◐		●=low landings; ○=high
Crab catch	1981-2003			⬀	●	◐	◐	◐	◐	○		●=low landings; ○=high
Shrimp – west coast of Vancouver Island	1972-2003		●	⊗	●	●	◐	○	○	●		●=low biomass; ○=high
Fishes												
Pelagics												
Coho salmon – British Columbia	1980-2003	○	○	⬃	●	●	●	●	●	●		●=low abundance; ○=high
Columbia River salmon	1940-2004	⊗	○	●	●	○	○	○	○	○	○	● = low returns; ○ = high
Pacific herring	1950-2003	⊗	⬃	●	●	●	●	◐	◐	◐		●=low biomass
Pacific sardine	1948-2003	absent	⬀	⬀	○	○	○	○	○	○		○=high biomass, recruitment
Pacific hake biomass	1948-2004	⬀	○	⬃	●	●	●	●	●	●	◐	●=low; ○=high
Pacific hake distribution	1948-2004	●	●	⬀	○	⬃	⬃	⬃	⬃	⬃	⬃	●=southerly distribution; ⬀=expanding; ⬃=contracting; ○=northerly
Gadids												
British Columbia Pacific cod	1956-2003	○	○	●	●	◐	○	◐	◐	◐		●=poor recruitment; ○=good
Rockfish												
California juvenile rockfish survey	1983-2002		○	⊗	●	●	⬀	⬀	○			●=poor recruitment; ○=good

	Length of time series	Regime 1948-1976	Regime 1977-1988	Regime 1989-1997	Year 1998	1999	2000	2001	2002	2003	2004	
Gulf of Alaska												
Physical Oceanography												
Gulf of Alaska sea surface temperature	1970-2002	●	⊗	⊗	○	◍	◍	◍	○			●=cool; ○=warm
Gulf of Alaska sea surface salinity	1970-2002	○	⊗	⊗	⊗	⊗	⊗	⊗	⊗			○=high
Northern British Columbia sea surface temperature	1948-2003	●	○	○	○	●	●	●	●	○		●=cool; ○=warm
Haida eddy occurrence	1993-2004			⊗	○	○	●	●	●	○	○	●=few eddies; ○=many
Gulf of Alaska mixed layer depth	1970-2002	⇔	⇔	⇔	⇔	⇔	⇔	⇔	⇔			⇔=no change in depth
Ocean Station Papa mixed layer depth	1957-2003	⊗	○	⊗	○	◍	◍	◍	○	○		○=shallow
Freshwater discharge	1930-2000	⇔	⇔	⇔	⇔	⇔	⇔					⇔=no change or trend
Lower Trophic Levels												
Nutrients	1998-2000				●	◍	○					●=low concentration; ○=high
Chlorophyll *a*	1998-2001				●	○	○	●				●=low concentration; ○=high
Gulf of Alaska zooplankton	1956-1962; 1980-89	●	○									●=low biomass; ○=high
Ocean Station Papa zooplankton timing	1970-2001		●	○	○	◍	◍	◍				●=late; ○=early
Invertebrates												
Shrimp survey	1973-2002	○	⇙	●	●	●	◍	◍	◍			●=low CPUE; ○=high
Crab fishery	1980-2002		◍	○	●	◍	◍	○	○			●=low CPUE; ○=high
Fishes												
Pelagics												
Southeast Alaska herring	1980-2002		●	◍	○	○	○	○	○			●=low biomass; ○=high
Northern British Columbia herring	1951-2003	⊗	⊗	⊗	◍	◍	◍	◍	◍	◍		●=low biomass; ○=high
Eulachon	1973-2002	⊗	⊗	●	●	●	●	●	○			●=low survey CPUE; ○=high
Capelin	1973-2002	○	⇙	●	●	●	●	●	●			●=close to zero survey CPUE
Alaska sockeye salmon	1900-2001	●	○	○	◍	○	◍	◍				●=low catch; ○=high
Alaska pink salmon	1900-2001	●	○	○	○	○	○	○				●=low catch; ○=high
Alaska coho salmon	1900-2001	●	○	○	○	○	○	○				●=low catch; ○=high
Northern British Columbia coho salmon	1980-2004		⇙	⇙	◍	◍	○	○	○	○		●=low abundance; ○=high

	Length of time series	Regime 1948-1976	Regime 1977-1988	Regime 1989-1997	Year 1998	1999	2000	2001	2002	2003	2004	
Gadids												
Walleye pollock	1967-2003	⬀	⊗	⬃	●	●	●	●	●	●		●=low biomass; ○=high
		○	○	●	●	○	◍	●				●=poor recruitment; ○=good
		○	◍	●	◍	○	○	●				●=low R/S survival; ○=high
Gulf of Alaska Pacific cod	1977-2001		⬀	⬃	●	●	●	●				●=low biomass; ○=high
			○	○	○	○	○	●				●=poor recruitment; ○=good
			○	◍	◍	◍	◍	●				●=low R/S survival; ○=high
Northern British Columbia Pacific cod	1956-2001	○	○	●	●	●	●	●				●=poor recruitment; ○=good
Gulf of Alaska sablefish	1960-2001	⊗	⊗	⬃	●	●	●	◍				●=low biomass; ○=high
		○	○	●	●	●	●	●				●=poor recruitment; ○=good
		⊗	○	○	●	●						●=low R/S survival; ○=high
Northern British Columbia sablefish	1976-1999		○	●	●	○						●=low R/S survival; ○=high
Flatfish												
Flathead sole	1981-1998		⬀	⬀	○							●=low biomass; ○=high
			○	○	○							●=poor recruitment; ○=good
			○	●	○							●=low R/S survival; ○=high
Central Gulf of Alaska halibut	1974-2004	●	⬀	⬀	⬃	⬃	⬃	⬃	⬃	⬃		●=low biomass; ○=high
		●	○	○	◍	◍	◍	◍	◍	◍	◍	●=poor recruitment; ○=good
Southeast Alaska halibut	1974-2004	●	⬀	⬀	○	○	○	○	○	○		●=low biomass; ○=high
		●	○	○	○	○	○	○	○	○	○	●=poor recruitment; ○=good
British Columbia halibut	1974-2004	●	⬀	⬀	○	○	○	○	○	○		●=low biomass; ○=high
		●	○	○	○	○	○	○	○	○	○	●=poor recruitment; ○=good
Arrowtooth flounder	1960-1997	●	⬀	⬀								●=low biomass; ○=high
		⬀	○	○								●=poor recruitment; ○=good
		⬀	○	●								●=low R/S survival; ○=high
Rockfish												
Gulf of Alaska Pacific ocean perch	1960-1998	⬃	●	⬃	◍							●=low biomass; ○=high
		○	○	○	◍							●=poor recruitment; ○=good
		●	○	○								●=low R/S survival; ○=high
Queen Charlotte Sound Pacific ocean perch	1962-1993	●	○	●								●=poor recruitment; ○=good
Bering Sea and Aleutian Islands												
Physical Oceanography												
Surface air temperature at St. Paul Island	1917-2004	●	○	○	○	◍	○	○	○	○	○	●=cold; ○=warm

	Length of time series	Regime 1948-1976	Regime 1977-1988	Regime 1989-1997	Year 1998	1999	2000	2001	2002	2003	2004	
Ice at 57°–58°N	1973-2003	○	⊗	⊗	●	●	⊗	none	●	none		●=less than 30%; ○=greater than 70%
Temperature (0–70 m) at M2	1995-2003			4°C	5°C	3°C	5°C	5°C	6°C	6°C		
Lower Trophic Levels												
Jellyfish	1982-2003		●	○	○	○	○	●	●	●		●=low biomass; ○=high
Invertebrates												
Benthos	1975-2000	○	◍	◍	○			◍				○=high survey CPUE
Eastern Bering Sea crab	1980-2002		⬃;⬀	⬃	◍	●	◍	◍	●			●=low total mature biomass; ○=high
Fishes												
Gadids												
Aleutian Islands walleye pollock	1977-2002		⬃ ⊗	⬀ ⊗	○ ◍	○ ◍	○ ◍	○ ◍	○ ◍			●=low biomass; ○=high ●=poor recruitment; ○=good
Eastern Bering Sea walleye pollock	1963-2002	● ⊗ ○	○ ⊗ ⬃	○ ⊗ ●	○ ◍ ◍	○ ◍ ◍	○ ◍ ●	○ ● ●	○ ● ●			●=low biomass; ○=high ●=poor recruitment; ○=good ●=low R/S survival; ○=high
Eastern Bering Sea Pacific cod	1978-2002		⬀ ⊗ ⬃	⬃ ⊗ ◍	◍ ◍ ◍	◍ ◍ ◍	○ ◍ ◍	● ◍ ◍	◍ ◍ ◍			●=low biomass; ○=high ●=poor recruitment; ○=good ●=low R/S survival; ○=high
Flatfish												
Eastern Bering Sea yellowfin sole	1960-1999	● ⬀ ⬀	⬀ ⊗ ⬃	⬃ ● ●								●=low biomass; ○=high ●=poor recruitment; ○=good ●=low R/S survival; ○=high
Bering Sea Greenland turbot	1973-2000	⊗	⬃ ⬃ ○	⬃ ● ●	● ● ◍	● ● ◍	● ● ◍					●=low biomass; ○=high ●=poor recruitment; ○=good ●=low R/S survival; ○=high
Eastern Bering Sea arrowtooth flounder	1974-1999	⬀ ⊗ ○	⬀ ⬃ ●	○ ◍ ●	○ ◍ ●	○ ◍ ●						●=low biomass; ○=high ●=poor recruitment; ○=good ●=low R/S survival; ○=high
Eastern Bering Sea rock sole	1971-1998	⬀ ⬀ ◍	⬀ ⬀ ◍	⬀ ⬃ ●	○ ● ●							●=low biomass; ○=high ●=poor recruitment; ○=good ●=low R/S survival; ○=high
Bering Sea flathead sole	1974-2001	⬀ ○ ○	⬀ ○ ○	⬃ ⬃ ●	○ ● ●	○ ● ●	○ ● ●	○ ● ●				●=low biomass; ○=high ●=poor recruitment; ○=good ●=low R/S survival; ○=high

	Length of time series	Regime 1948-1976	Regime 1977-1988	Regime 1989-1997	Year 1998	1999	2000	2001	2002	2003	2004	
Rockfish												
Eastern Bering Sea and Aleutian Islands Pacific ocean perch	1960-1993	↙ ● ●	↗ ◍ ○	↗ ◍ ●								●=low biomass; ○=high ●=poor recruitment; ○=good ●=low R/S survival; ○=high
Higher Trophic Levels												
Pribilof fur seals	1975-1998	○	↙	●	●							●=low pup survival; ○=high
Western North Pacific												
Sea of Okhotsk												
Physical Oceanography												
Sea ice coverage	1930-2002	○	↙	●	●	○	○	○	○			●=low extent; ○=high extent
Sea temperature at 50-200m	1996-2000			○	○	●	●					●=cold; ○=warm
Lower Trophic Levels												
Summer–fall zooplankton	1984; 1986; 1988; 1997-2002		○	●	●	○	○	○				●=low biomass; ○=high
Fishes												
Pelagics												
Herring	1985; 1986; 1988; 1998-2002		⊗		○	○	◍	◍	◍			●=lower proportion of epipelagic community; ○=higher proportion
Capelin	1985; 1986; 1988; 1998-2002		●		●	●	●	○	○			●=lower proportion of epipelagic community; ○=higher proportion
Gadids												
Walleye pollock	1984-1999		○	◍	●	●						●=low spawning biomass; ○=high
Tsushima Current Region												
Physical Oceanography												
Sea surface temperature off coastal Hokkaido	1965-2001	○	●	○	●	●	●	●				●=negative anomaly; ○=positive
Sea surface temperature off coastal Honshu	1965-2001	◍	●	○	○	○	○	○				●=negative anomaly; ○=positive
Sea surface temperature off coastal Korea	1968-2002	⊗	●	○	○	○	○	○	○			●=negative anomaly; ○=positive
Winter sea temperature at 50 m depth in western Sea of Japan	1965-2003	●	●	○	○	○	○	○	○	○		●=negative anomaly; ○=positive

	Length of time series	Regime 1948-1976	Regime 1977-1988	Regime 1989-1997	Year 1998	1999	2000	2001	2002	2003	2004	
Lower Trophic												
Primary production off coastal Korea	1960-1990	○	●									●=negative anomaly; ○=positive
Zooplankton abundance off coastal Korea	1960-1990	○	●									●=negative anomaly; ○=positive
Invertebrates												
Common squid fishery	1973-2003	◍	●	⬀	●	○	○	○	○	○		●=low CPUE; ○=high
Fishes												
Pelagics												
Jack mackerel	1973-2002	◍	⬀	○	○	○	○	○	○			●=low biomass; ○=high
		●	●	⊗	●	●	●	●	●			●=low R/S survival; ○=high
Chub mackerel	1973-2002	○	○	⬀	●	●	●	●	●			●=low biomass; ○=high
		○	⬃	◍	○	○	○	○	○			●=low R/S survival; ○=high
Spotted mackerel	1992-2002			◍	○	○	○	○	○			●=low biomass; ○=high
				⊗	○	●	●	●	●			●=low R/S survival; ○=high
Japanese sardine	1988-2002			⬃	●	●	●	●	●			●=low biomass; ○=high
				●	○	●	◍	○	○			●=low R/S survival; ○=high
Anchovy	1988-2002			⬀	○	○	◍	●	●			●=low biomass; ○=high
				⊗	●	●	◍	○	◍			●=low R/S survival; ○=high
Round herring	1991-2002			⬃	◍	◍	●	●	●			●=low biomass; ○=high
				⊗	◍	◍	◍	○	○			●=low R/S survival; ○=high
Higher Trophic Levels												
Hokkaido seabirds	1984-2001		●	○	○	○	○	○	○			●=sardine dominant diet; ○=anchovy
Kuroshio-Oyashio Current Region												
Physical Oceanography												
Spatial extent of Oyashio Current	1960-2003	●	○	○	◍	●	●	○	○	○		●=negative area anomaly; ○=positive area anomaly
Winter sea surface temperature in Kuroshio	1950-2002	●	⊗	○	○	○	◍	○				●=cool; ○=warm
Lower Trophic Levels												
Oyashio zooplankton	1972-1999	○	●	⊗	●	●						●=low biomass; ○=high
Fishes												
Pelagics												
Chub mackerel	1950-2001	○	⬃	●	●	●	●	●				●=low biomass; ○=high
		○	◍	⊗	●	●	◍	●				●=low R/S survival; ○=high

	Length of time series	Regime 1948-1976	Regime 1977-1988	Regime 1989-1997	Year 1998	1999	2000	2001	2002	2003	2004	
Japanese sardine	1950-2001	⇗ ○	○ ◍	⇙ ●	● ◍	● ●	● ◍	● ●				●=low biomass; ○=high ●=low R/S survival; ○=high
Pacific saury	1980-2002		⇗	○	●	●	●	◍	●			●=low commercial CPUE; ○=high
Yellow Sea and East China Sea												
Physical Oceanography												
Sea surface temperature off Korean coast	1965-2002	●	⊗	⇗	○	○	○	◍	◍			●=cool; ○=warm
Air temperature at Quingdao	1950-2003	●	◍	○	○	○	○	○	○			●=cool; ○=warm
Bohai Sea nutrient concentrations	1959; 1982; 1992	◍ ◍ ○	◍ ◍ ○	◍ ● ●								●=low nitrogen; ○=high ●=low phosphate; ○=high ●=low silicate; ○=high
Lower Trophic Levels												
Bohai Sea phytoplankton	1982; 1992; 1998		○	◍	●							●=low primary productivity; ○=high
Bohai Sea zooplankton	1959; 1982; 1992; 1998	◍	◍	●	○							●=low biomass; ○=high
Yellow Sea zooplankton	1978-2001		●	○	○	○	○	○				●=low biomass; ○=high
Fishes												
Pelagics												
Yellow sea anchovy	1954-2001	●	⇗	⇗	○	○	○	◍				●=low biomass; ○=high
Pacific herring	1968-1976	◍	●	●	●							●=very low biomass, no fishery
Demersal Fishes	1960-2002	○	⇙	●	●	●	●	●	●			●=low proportion in fish community; ○=high